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Use of the Square-Root Method to Identify Factors in the Job Performance of Aircraft Mechanics[1]

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I. INTRODUCTION

THIS report has a threefold purpose: (*a*) to exemplify application of a modified version[5] of square-root factor analysis to a large correlation matrix, (*b*) to describe the factorial structure of job performance ratings obtained from supervisors of aircraft mechanics,[6] and (*c*) to compare the results of this study with those of two earlier and similar investigations (6, 7) in order to determine the most appropriate source of items for the rating of job performance in the field of aircraft maintenance.

Taking up the third purpose first, it should be explained that in the first study of the series (7), the descriptive items to rate job performance were obtained from interviews with supervisors of aircraft mechanics. In the second (6), items were selected from a wide variety of factor analyses of personality traits appearing in the psychological literature. In the third, reported here, items were drawn from existing rating scales and questionnaires designed to measure various aspects of job performance.

Each phase of the research led to preparation of a different inventory intended for use as a rating device. The development and analysis of each inventory was conducted in accordance with the same general plan. An inventory of 200 items was obtained by assembling

[1] This research was supported in part by the United States Air Force under Contract No. 33-(038)-25726 monitored by the Air Force Personnel and Training Research Center. Permission is granted for reproduction, translation, publication, use, and disposal in whole and in part by or for the United States Government.

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[4] This study was a cooperative project whose completion depended upon the assistance of many persons. Kern W. Dickman and Mrs. Carol R. Tucker carried out the statistical analyses. Mr. Dickman also prepared a computer program for rank-ordering sets of correlations and factor loadings which greatly reduced the amount of hand computation required. Ramona J. Russell and William L. Huffman supervised the computer operations, and Robert D. Boys and Marvin I. Knopp assembled and organized the statistical results. The authors wish to express their sincere appreciation to the persons named for their assistance and cooperation.

[5] The modified square-root method of factor analysis was developed by Wrigley and McQuitty (9) in an attempt to meet certain criticisms customarily advanced against the square-root method, with a view to making factor analysis more readily applicable to large correlation matrices. The nature and purposes of the changes are briefly described in Section III of this report.

[6] The subjects of this study were Air Force Aircraft and Engine Mechanics. To conserve space, they will throughout be referred to as "aircraft mechanics."

a pool of items and revising a sample of them. This was administered to a large sample of supervisors of aircraft mechanics. (*N*'s for the three studies ranged from 383 to 464.) Approximately one quarter of the subjects in each sample were asked to describe a "best," one half to describe an "average," and one quarter to describe a "poorest" mechanic, by responding "true" or "false" to the inventory items. Each inventory was then factorized in order to permit the development of a single, more comprehensive inventory in which overlapping of items in terms of factorial content would be minimal.

It should be noted here that while in principle factor analysis is generally considered to be the most satisfactory procedure currently available for reducing the number of items or variables with least loss of information, it suffers from a serious limitation, namely, computations are simply too laborious for application to any very large set of variables. In the present series of studies, where so many items had be considered, a simpler procedure was needed than calculation and rotation of a centroid or a multiple-group factor analysis. The modified square-root method was accordingly used. A virtue of this procedure is that it can be applied without incommensurate labor to as many as 200 or 250 variables, provided reasonably good computational facilities are available. Because of its potential usefulness in other studies where the number of variables to be analyzed is very large, this report is devoted in part to a brief description of the method.

The organization of this monograph is as follows: The second section describes the preparation and administration of the job performance inventory, the third describes the square-root method of factor analysis, and the fourth and fifth sections present the results of the statistical analyses of the data. In the sixth section, results of the present study are compared with those of the two which preceded it in the series. The study is summarized in the seventh and final section.

II. Preparation and Administration of the "Survey Inventory"

The psychological literature contains many rating scales and questionnaires designed to measure various aspects of vocational proficiency. Few of these studies refer directly to the selection of mechanics. However, many deal with jobs which appear to be somewhat similar, and include items referring to traits of possible importance to success in aircraft maintenance work.

It was therefore hypothesized that items drawn from these studies would be useful for describing job performance of aircraft mechanics. The content of these scales is broad in scope, and each item reflects the accumulated experience of one or more experts in personnel psychology. Appropriate sampling of this material should thus contribute to the attempt to isolate characteristics related to efficient aircraft maintenance.

Collection and sampling of the item pool. In order to locate pertinent studies, the *Psychological Index* and *Psychological Abstracts* from 1900 to 1952 were consulted for articles containing relevant rating scales and questionnaires. The search yielded 64 studies containing descriptive phrases which appeared to be related to the on-the-job behavior of aircraft mechanics. From these sources, some 3,365 items were chosen.

These items were then classified into

42 content categories according to a method developed by Staugas and McQuitty (8), and a stratified sample was drawn from the pool in such a way as to minimize overlap with the two preceding inventories. In selecting items for the sample, preference was given to those which (*a*) were expressed in simple language and (*b*) appeared to represent most clearly the essence of the category into which they had been classified. To allow for rejection of items which might prove unsatisfactory upon preliminary administration, 221 rather than 200 items were initially selected from the pool.

Modification of items and assembly of the inventory. In assembling the inventory, the aim was to retain each item in the exact form in which it was written whenever possible, and if any alterations in wording had to be made, to insure that the original meaning of the item remained unchanged. The following types of editorial revisions were made:

1. Items calling for self-judgments were changed to a form requiring judgments of others. This was done because the inventory was intended for use by supervisors for the rating of line workers.
2. Items referring to supervisory personnel were modified for application to line mechanics.
3. Items relating to civilian jobs were reworded to apply more specifically to Air Force maintenance work.
4. Items designed for females were changed to apply to males.
5. Items in the form of a question were turned into declarative statements.
6. Some items were shortened to improve their clarity.
7. The grammatical form was rendered consistent from item to item.
8. Words judged by the investigators to be difficult were replaced by words believed to be more commensurate with the educational attainments of the average Air Force mechanic.
9. In a "double-barrelled" item, the more general phrase of the two was retained, and the qualifying, subordinate, or more specific phrase eliminated.
10. All items were cast into the present or the conditional tense for consistency and ease of interpretation.

Upon completion of editing, the phrases were assembled into a preliminary inventory and administered individually to 28 aircraft mechanics, all of whom had had at least six months of experience on the line. Half of these subjects were asked to rate the "best" and half were requested to rate the "poorest" mechanic with whom they had worked, by checking "true" or "false" for each phrase in the inventory. (The two-point scale of "true" and "false" was decided upon because of our intention to use phi coefficients in the factor analysis.) The entire group of subjects was encouraged to make comments on the individual items.

After the responses had been tallied, chi square was calculated for each item in order to locate those which failed to discriminate significantly between the descriptions of "best" and "poorest" mechanics. The items were then reviewed by three judges. Those which met *all* of the following conditions were retained without modification:

1. The chi-square value was significant at the .05 level.
2. No comment concerning either wording or understanding of the item was offered during individual administration.
3. Neither answer alternative to the item was endorsed by fewer than 10 per cent of the subjects.

These requirements were met by 167 of the items. The remaining items were considered one at a time with respect to the above three criteria. Items with less than a 10 per cent response for either answer alternative were rewritten to enlarge this percentage whenever this appeared possible; otherwise they were re-

jected. Items which mechanics reported as requiring information that they did not have were rejected, and those difficult to understand were amended. This procedure yielded a final inventory of 200 items, named by us the Survey Inventory. This is the instrument used in all subsequent phases of this study. It is reproduced in the Appendix.

Administration of the inventory. To obtain data for the factor analysis, the inventory was administered to 464 supervisors of aircraft mechanics from Chanute, Sheppard, and Connally Air Force Bases. In this administration, 148 supervisors were asked to describe the "best," 179 were asked to describe an "average," and 137 were asked to describe the "poorest" mechanic with whom they had worked during the previous two years. The inventory was given in small group sessions (10 to 30 men) of about 30 minutes in length. This allowed ample time for all subjects to complete the items.

For each subject, the following occupational experience was required: (*a*) completion of the basic training course for aircraft mechanics; and (*b*) at least six months' experience as a supervisor of aircraft mechanics.

The data obtained in this phase of the study were then subjected to a modified square-root factor analysis. These results are presented in Section IV.

III. The Square-Root Method of Factor Analysis

The standard methods of factor analysis are generally agreed to be too laborious to be readily applicable to a correlation matrix much larger than 100 variables. Yet there are occasions when it would be desirable to analyze correlation matrices of a size considerably larger than this. The square-root method of factor analysis (sometimes known as the diagonal method) is the simplest factor-analytic procedure, but has not won widespread favor because of various criticisms advanced against it. The method has accordingly been modified by Wrigley and McQuitty (9) in an attempt to meet these criticisms; in the course of doing so, the computations have been still further simplified.

Our restricted objective in making these modifications should be made quite explicit. The intention was not to provide a method which is in any sense to be regarded as a competitor of standard methods; the purpose was merely to provide some way of analyzing correlation matrices too large for the regular procedures. Hence it is not incumbent upon us to demonstrate that our solution is as satisfactory as, say, a simple structure solution would be, even were it possible to do so. It suffices if we can demonstrate that square-root factors are generally interpretable and psychologically meaningful, and add in some measure to our understanding of the structural interrelations of the variables analyzed.

The square-root method. First let us briefly summarize the standard form of the square-root method as well as the criticisms which have been made of it. The first step in the procedure is to calculate loadings for a first factor in such a way as to reduce all residual correlations with a selected *pivot variable* to zero. This is equivalent to placing a reference axis collinear with the test vector of the pivot variable. Residual correlations are then calculated in the usual way. This implies projection of the test vectors onto a plane orthogonal to the reference axis. In the next step, loadings are calculated for a second fac-

tor so that residual correlations for a second pivot variable are reduced to zero. The second axis will be collinear to the *residual* test vector of the second pivot variable, and will be at right angles to the first. The second set of residual correlations is calculated, and so the method proceeds. Since successive reference axes are at right angles, the factors are mutually orthogonal, so that the factor measurements for the persons in the sample, if calculated, would be uncorrelated.

The computational formula for square-root loadings is simple. The factor loading f_{i1} for the ith variable on the first factor is:

$$f_{i1} = \frac{r_{iq}}{\sqrt{r_{qq}}}, \qquad [1]$$

where r_{iq} is the correlation of the ith variable with the pivot variable q and r_{qq} is the diagonal entry for the pivot variable.

More generally, the loading for the jth factor, with pivot variable s, is:

$$f_{ij} = \frac{r_{is}^{(j-1)}}{\sqrt{r_{ss}^{(j-1)}}}, \qquad [2]$$

where $r_{is}^{(j-1)}$, $r_{ss}^{(j-1)}$ are the residual correlations for the $(j\text{-}1)$th factor.

Criticisms of the method. There have been two main criticisms of the square-root method:

1. The procedure depends to a greater extent than most other factor-analytic methods upon accurate estimation of the communalities, since diagonal entries play such an important role in calculating the factor loadings. If some communalities are underestimated, then some diagonal entries may become negative during the calculations. This means that one must take the square root of a negative number, which results in factor loadings which are imaginary.

2. The order of selection of pivot variables is unspecified, so that p factorial solutions are possible (where $p =$ the number of variables). No rule is provided for selecting any one order of pivot selection in preference to any other.

The modified procedure. Our modifications were intended to provide (*a*) a logical basis for specifying order of selection of pivot variables, (*b*) a method not dependent in any way upon the arbitrary judgment of the investigator, and (*c*) a computational procedure rapid enough to permit the handling of large correlation matrices. The following three modifications have accordingly been introduced:

1. Unities are inserted in the leading diagonal in place of communalities. This insures that so long as product-moment correlations are analyzed, no diagonal entry can become negative during the calculation.[1] (Phi coefficients and point biserials will be remembered to be special forms of product-moment correlation.)

It is true that if unities are used, the factors obtained include specific as well as common variance. There are some who have doubted whether any factors derived by the use of unities rather than communalities can be psychologically meaningful. Our experience has been that they are interpretable. It will be noted that the specific variance in any factor is restricted to the loading for the pivot variable. The other loadings represent only common variance. (It can be shown that the sum of squares of loadings for any nonpivot variable is equal to the squared multiple correlation with the set of pivot variables, i.e., is a measure of common variance only.) An incidental result of using unities is that factor measurements, if required, can be calculated exactly instead of having to be estimated, as is necessary in any communalities solution (5, ch. 12).

2. The variable with the largest sum of off-diagonal correlations (and subsequent residual correlations) is selected as the pivot variable. This provides an objective criterion for pivoting order, and insures every factor will have some large loadings and that these will be predominantly positive.

3. A formula, based upon an algebraic identity, was developed for calculating the sum of residual correlations for each variable without having to compute each individual residual. In the extraction of each factor, therefore, there must be calculated only the p column-sums, followed by p residuals for the indicated pivot

[1] Ford, L. R., Jr. A proof that the matrices of certain indices of association are Gramian. Unpublished manuscript, 1952.

variable, instead of the usual $p(p+1)/2$ residual correlations.

Nonrotation of square-root factors. Rotation is generally essential for a principal axes or a centroid solution because the axes tend to pass between, rather than through, the test clusters. In the square-root method, however, the reference axes are placed collinear with the pivot variables. Hence if each pivot lies in a fairly central position in a cluster, the reference axis will pass *through the cluster.* This generally turns out to be the case, since in the present method the pivot variables are selected on grounds of their high column-sums. For this reason, no rotation of the factor loadings is considered necessary.

Parenthetically, it should be noted that when the data are dichotomous, our preference is for calculating phi coefficients rather than tetrachoric correlations. The correlation matrix is then necessarily Gramian, so that no diagonal entry can become negative in the course of the analysis (unless as a result of rounding errors).

The amount of variance accounted for by any factor in an orthogonal solution is, as is well known, a function of the sum of squares of the loadings. In the principal axes method, the sum of squares of each successive factor is necessarily equal to or smaller than those for preceding factors, and this relation is generally true for the centroid method. In our method of analysis, factors are not necessarily extracted in order of contribution of variance. However, because of pivot selection depending on column sums, there is a marked tendency for larger factors to be extracted first and smaller factors later. (See Table 1 for evidence of this progression.) Our computational procedure has been to extract more factors than needed, this being practicable because of the speed of the method, and then to order them according to sums of squares of loadings, retaining and reporting only the larger ones.

The generally smaller size of square-root loadings. The square-root loadings obtained by the above procedure tend, in general, to be lower than would be obtained by a standard solution, such as a simple structure rotation of a centroid analysis of tetrachoric correlations. There are three main reasons for this:

1. Phi coefficients are generally smaller than tetrachoric correlations.

2. Even for the same correlation matrix, square-root loadings tend to be lower than centroid loadings. The sum of squares of loadings for any nonpivot variable in a square-root solution can be shown to be equal to the squared multiple correlation (SMC) of that veriable with the k pivot variables. But the SMC of any variable with the k pivot variables only is necessarily less than or equal to the SMC of the variable with the full set of $(p-1)$ other variables in the analysis. Guttman (4, pp. 92-93) has shown this latter to constitute a lower bound for the communality. Hence the sum of squares of loadings for any nonpivot variable is necessarily less than or equal to the communality. In practice it is generally appreciably less.

3. A general factor is more likely in a square root than in a simple structure solution, for the reason that the variable with largest column-sum is usually some rather generalized measure. Because more variance is accounted for by the first factor, less therefore remains to define later factors.

Any new psychometric procedure has to establish two points: (*a*) its computational feasibility, and (*b*) its psychological usefulness. The first requirement is clearly met in the present instance. The modified square-root method is considerably more rapid than any other factor-analytic procedure currently available, primarily because there is no longer any problem either of reflection or of rotation. In addition, the number of residual

correlations to be calculated in extracting each factor is much reduced. The computational gain is particularly evident on an electronic computer. On Illiac (the University of Illinois computer), approximately six factors can be extracted from a correlation matrix of order 200 in an hour. This time refers, of course, only to machine operation, and much further time may be needed for preparing tapes, printing results, etc. Even so, the factor analysis of a large correlation matrix becomes quite feasible.

The main problem is therefore whether the classification of variables provided by the square-root method is psychologically meaningful, although unities have been inserted in the diagonal, so that results may properly be used to reduce the number of variables to more manageable proportions. The data in the next section provide some of the evidence in support of our assertion that the factors provided by the modified square-root method are both interpretable and informative.

IV. Results of the Factor Analysis

In obtaining the phi coefficients for the factor analysis, all subjects (whether classified as "best," "average," or "poorest" mechanics) were included in a single sample. The square-root factor analysis of the phi coefficients was continued until 40 factors had been extracted. This extensive factoring was carried out to determine (*a*) the relative size of the successive factors, and (*b*) the number of square-root factors which appear to be psychologically meaningful, in a correlation matrix as large as this.

Table 1 presents sums of squares of loadings for the 40 factors and indicates their order of extraction. These factors

TABLE 1

Square-Root Factor Analysis: Sums of Squares of Factor Loadings

Factor in order of size	Factor in order of extraction	Sum of squares of factor loadings	Factor in order of size	Factor in order of extraction	Sum of squares of factor loadings
1	1	53.6714	21	17	1.3461
2	5	9.2086	22	16	1.3385
3	2	7.7215	23	18	1.3249
4	6	3.3000	24	27	1.2734
5	8	2.9307	25	25	1.2705
6	3	2.8628	26	28	1.2492
7	4	2.1757	27	21	1.1665
8	9	2.0308	28	23	1.1340
9	12	1.8699	29	38	1.1257
10	14	1.8280	30	36	1.0196
11	13	1.7899	31	26	.9507
12	29	1.7800	32	31	.9473
13	11	1.7171	33	32	.9434
14	7	1.6961	34	33	.9228
15	15	1.5903	35	35	.9169
16	22	1.5618	36	30	.9121
17	24	1.5545	37	34	.8230
18	19	1.5001	38	40	.8139
19	20	1.4529	39	39	.7894
20	10	1.4250	40	37	.7411

Factors	Sum of squares of factor loadings	Percentage contribution to total variance
1	53.6714	26.8%
2–10	33.9286	17.0
11–20	16.0767	8.0
21–30	12.2483	6.1
31–40	8.7606	4.4
Remaining variance	75.3144	37.7
Total (200 items)	200.0000	100.0%

together account for 62.3 per cent of the total variance. The total variance is based upon all items, and is equal to the number of items, since each item has been taken to have unit variance. If all factors had been extracted, the total sum of squares of loadings would have equalled the total variance (i.e., 200).

The 28 largest of the extracted factors appeared sufficiently meaningful to be named. However, owing to space limitations, only the first ten will be reported here.[8] A second restriction involves the

[8] A 19-page description of Factors 11 to 28 has been deposited with the American Documentation Institute. Order Document No. 4839 from ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D.C., remitting in advance $1.75 for microfilm or $2.50 for 25 photocopies. Make checks payable to Chief, Photoduplication Service, Library of Congress.

number of loadings presented for each factor. It is customary, in reporting factorial studies, to present all variables with loadings equal to or greater than a stated size—often .30—and to exclude all with loadings less than that. In this study, however, there were 173 loadings above .30 for the first factor, so that we have reported only the highest 30, since these suffice to describe the factor. With respect to the remaining factors, the conventional cutoff point of .30 would be inappropriate because, as previously pointed out, the square-root loadings for factors subsequent to the first are lower than their simple structure counterparts. We have therefore uniformly used the ten highest loadings, even when lower than .30, to determine whether the factor is meaningful.

In the following discussion we shall use the term *criterion correlation* to designate the phi coefficient between the "true" or "false" responses to each item and the supervisors' classifications of the mechanics as either "best" or "poorest," i.e., excluding "average" mechanics from the sample. The primary reason for excluding them in calculating these coefficients was the availability of an electronic computer program for dichotomous data. Exclusion of the average group was preferred to combining it with one of the other classes because we were interested only in the *comparative* indices of validity. By computing the criterion correlations on the extreme cases only, the interitem comparisons were made as sharp as possible.

It will no doubt be apparent that these criterion correlations are probably heavily loaded by halo effects. When the supervisor selects a "poorest" mechanic for description, he is obviously likely to describe him as using good judgment in most situations, or as being respected by his co-workers. However, the probable existence of such effects does not make the criterion correlations valueless. By means of the criterion correlations, we can determine which attributes form part of the supervisors' global impressions (or halo effects) and which do not.

The ten largest factors obtained by the square-root analysis will now be reported.

Factor 1. General Job Efficiency

Item number	Loading	Criterion correlation	Descriptive phrase
86	1.000	.775	Does jobs in order of importance
187	.764	.870	Fits well into the organization
116	.732	.865	Goes over own work to see that it was done correctly
161	.722	.816	Works well without supervision
131	.720	.809	Sees what will be needed later and gets ready for it
8	.693	.857	Seems to have a good future as a mechanic
169	.691	.812	Works well without a lot of explaining
123	.688	.799	On the lookout for better ways of doing the job
180	.688	.838	He gives his best effort to whatever he is doing
191	.688	.846	Sets a good example through his habits of work
163	.686	.834	Handles additional and special responsibilities well
92	.684	.834	He should develop into one of the leading men in the crew
145	.684	.808	Can take over in an emergency
179	.683	.807	Is determined to make good
200	.680	.784	Is always a willing worker
91	.671	.836	Very valuable in a new operation
106	.669	.791	Very good at going ahead alone
152	.667	.773	Respected by all who know him
144	.666	.745	Helps others with their work whenever possible
90	.664	.731	Selects proper Tech. Orders and makes correct use of them
111	.662	.797	He makes the best use of his ability
34	.657	.769	Uses good judgment in most situations
174	.657	.811	Knows how to organize to get right things done at right time
114	−.686	−.806	Loses too much time in waste motion
170	−.676	−.799	Never has things ready when needed
121	−.670	−.795	Always ready with an excuse
66	−.664	−.798	Seldom plans work ahead
65	−.659	−.824	Takes far too many breaks
88	−.659	−.797	Never notices things to be done
95	−.656	−.848	Doesn't do his share of the work

The criterion correlations are uniformly large for highly loaded items on this first square-root factor. The factor might perhaps be interpreted as the statistical representation of halo effects, and given the label of "General Success on the Job." Our reason for not doing so is that we believe this title is too broad, and does not make clear the psychological nature of this general factor. The term "General Job Efficiency" was chosen instead, as better representing the essential import of the factor. The listed items stress the mechanic's ability to organize his schedule so that his own work is coordinated with that of others and so that the more important jobs are done first. Such a mechanic can work by himself without detailed explanation or constant supervision. His working habits are good, and we are told that he gives his best effort to whatever he is doing, a characteristic suggesting that his efficiency is a function of high motivation as well as of sound organization. The factor is perhaps more revealing in terms of what is omitted than what is included. It should be noted that little is said explicitly about the mechanic's manual dexterity or his knowledge of his job, and no reference is made to his social relations with the other mechanics, or to his emotional structuring. In this factor, the stress seems to be not on what the mechanic himself is like, but rather on his capacity for working efficiently and making good use of the skills at his command.

Factor 2. Social Maladjustment

Item number	Loading	Criterion correlation	Descriptive phrase
148	.769	−.736	Exaggerates too much
112	.386	−.703	Uses a "line" to try to impress others
146	.364	−.780	Wastes time walking around and talking to others
81	.356	−.653	Rubs people the wrong way
142	.351	−.673	Makes trouble over little things
184	.349	−.694	Always wanting sympathy
139	.324	−.483	He butts in on others' responsibilities
130	.321	−.752	Says one thing and does another
173	.319	−.507	Tries to flatter crew chief
200	−.318	.784	Is always a willing worker

This factor stresses personality inadequacies which result in unpopularity and generally poor interpersonal relations. The over-all flavor is one of immaturity, self-centeredness, and obtrusiveness. It should be noted that the traits described tend to be correlated with disinclination for work.

Factor 3. Executive Ability

Item number	Loading	Criterion correlation	Descriptive phrase
166	.827	.621	Discusses plans frequently with superior
181	.316	.594	An extremely good organizer of personnel
163	.310	.834	Handles additional and special responsibilities well
49	.304	.635	Seeks and does additional tasks beyond those required
174	.286	.811	Knows how to organize to get right things done at right time
92	.284	.834	He should develop into one of the leading men of the crew
191	.280	.846	Sets a good example through his habits of work
165	.275	.612	Quick to praise a man for a job well done
122	−.282	−.568	Goes his own way regardless of others
136	−.275	−.621	Dissatisfied with his present job

Factor 3 defines the ability to organize activities and personnel and to spur cooperative achievement. The emphasis is not so much on the tendency to direct and dominate others as on the capacity for responsible supervision and effective administration.

Factor 4. Leadership

Item number	Loading	Criterion correlation	Descriptive phrase
63	.822	.641	He is apt to be master of a situation if it needs a leader
21	.267	.505	Likes to take on responsibilities
189	.256	.523	He is good at organizing new activities
134	.255	.659	Plans ahead for almost any emergency
60	.253	.449	He makes definite decisions and defends them with courage
181	.251	.594	An extremely good organizer of personnel
4	.243	.364	Likes to make decisions
106	.212	.791	Very good at going ahead alone
182	−.271	−.407	Prefers to be a follower rather than a leader
67	−.208	−.795	Doesn't seem to realize he's just a cog in a large wheel

Factor 4 stresses decisiveness, initiative, and the tendency to assume a dominant role in leaderless situations. Here the emphasis is on liking for responsibility and decision-making, that is to say, for giving directions rather than executing them. The factor appears to conform to traditional definitions of leadership.

Factor 5. Personal Charm

Item number	Loading	Criterion correlation	Descriptive phrase
107	.878	.363	Always pleasant and cheerful
71	.302	.171	Has a pleasant voice
76	.282	.352	Easy to talk to
176	.266	.460	He is considered a "good sport"
101	.251	.070	Easy going
9	.242	.340	Takes pride in his health
19	.239	.064	Usually sees the humorous side of things
80	.235	.472	Tends to see the good side of things
57	−.253	−.341	Is inclined to be impatient with others
93	−.235	−.376	Inclined to "pop off" on occasion

These items define a pleasant, relaxed, approachable personality with a predominant tone of cheerfulness and good humor.

Factor 6. Resourcefulness

Item number	Loading	Criterion correlation	Descriptive phrase
158	.899	.434	Able to by-pass red tape when necessary
68	.230	.627	Is familiar with main trouble spots of an airplane
168	.226	.647	Will really go to bat for things when he has to
73	.222	.659	Usually finds some way to "crack a hard nut"
51	.216	.788	His advice is asked by others
45	.208	.649	Stimulates co-workers to think
177	.200	.372	Teaches himself how to operate equipment without supervision
33	.197	.721	He learns new jobs quickly
22	.183	.349	Has a good imagination
135	−.187	−.574	Is helpless when working in awkward positions

Ingenuity and resourcefulness appear to form the central core of this factor, with good job knowledge, superior learning ability, and an imaginative approach to problem-solving also associated.

Factor 7. Willingness and Adaptability

Item number	Loading	Criterion correlation	Descriptive phrase
140	.832	.504	Would be willing to begin in any kind of job to prove his ability
115	.201	.665	Wants to adjust himself to new situations
144	.186	.745	Helps others with their work whenever possible
179	.176	.807	Is determined to make good
107	.174	.363	Always pleasant and cheerful
28	.172	.705	Usually tackles a job with enthusiasm
119	.167	.611	Takes pride in group accomplishment
102	.164	.690	Turns off power or motor equipment when not in use
13	.160	.661	Can be used effectively on several different types of work
180	.153	.838	He gives his best effort to whatever he is doing

This factor emphasizes willingness, determination, and adaptability. The items portray the type of mechanic who wants to make good and prove his own capabilities. Eager to tackle new problems, he has high morale and takes pride in group accomplishment. It is hardly surprising to find that such an individual often helps others. Though we cannot be sure as to the psychological reasons for this energetic service, one is inclined to speculate that the mechanics so described are by nature eager and compliant, and that it is this, rather than any overwhelming interest or ambition, which is responsible for their willingness.

Factor 8. Orderliness

Item number	Loading	Criterion correlation	Descriptive phrase
197	.806	.516	Knows his own abilities well
74	.217	.702	He accepts full responsibility for his own work
159	.168	.716	Usually assembles or disassembles parts in proper sequence
73	.160	.659	Usually finds some way to "crack a hard nut"
71	.158	.171	Has a pleasant voice
147	.157	.570	His quarters are usually neat
137	−.166	−.437	Is careless of personal appearance
10	−.165	−.564	Couldn't direct without irritating people
54	−.154	−.467	Hesitates in making decisions on ordinary everyday questions
135	−.150	−.574	Is helpless when working in awkward positions

At first sight, the items appearing under this factor are much more heterogeneous than those in the seven preceding it. We find here clustering together such varied characteristics as neatness, self-direction, insight, a pleasant voice, and accuracy in performance on the job. This diversity of item content can hardly be attributed to sampling error, as we find that factors with considerably less variance than this are nevertheless consistent and meaningful. We have accordingly hypothesized that this factor defines a personality trait making for precision and exactness in thought and action. A mechanic having this trait knows his own mind and capacities, is neat and orderly in appearance, and takes a systematic approach to his work. He is methodical, but not without ingenuity, and can direct others without irritating them. In general, the impression given is of an individual who is well organized but not compulsive, careful but not finicky. This factor is an interesting one whose constituent items tend for the most part to correlate reasonably well with our criterion of job success.

Factor 9. Ability to Motivate Others

Item number	Loading	Criterion correlation	Descriptive phrase
171	.657	.715	Provides just the "spark" that is needed for effective teamwork
183	.209	.613	Makes allowance for the limitations of others
18	.204	.685	Arouses ambition in fellow mechanics
151	.192	.669	He has made a good social adjustment on the job
45	.190	.649	Stimulates co-workers to think
165	.187	.612	Quick to praise a man for a job well done
83	.185	.641	Boosts the morale of any group in which he is working
152	.179	.773	Respected by all who know him
189	.175	.523	He is good at organizing new activities
67	−.170	−.795	Doesn't seem to realize he's just a cog in a large wheel

Together these items describe the responsible, task-oriented mechanic with a talent for group activity. His attitude toward the job and ability to organize make for effective teamwork among his co-workers.

Factor 10. Mechanical Proficiency

Item number	Loading	Criterion correlation	Descriptive phrase
73	.707	.659	Usually finds some way to "crack a hard nut"
34	.194	.769	Uses good judgment in most situations
159	.185	.716	Usually assembles or disassembles parts in proper sequence
61	.178	.728	He can organize his ideas effectively
68	.176	.627	Is familiar with main trouble spots of an airplane
13	.172	.661	Can be used effectively on several different types of work
33	.159	.721	He learns new jobs quickly
115	.158	.665	Wants to adjust himself to new situations
15	−.186	−.683	Doesn't listen to suggestions
95	−.172	−.848	Doesn't do his share of the work

In this factor the primary emphasis is upon proficiency and the ability to cope with mechanical problems. However, the psychological nature of this proficiency is defined only in the broadest of terms. Reference is made to ingenuity and good judgment, to versatility, adaptiveness, and, indirectly, to job knowledge. Motivational requirements are also mentioned, as they were in Factor 1. Supervisors do not seem to make the distinction between motivational and cognitive qualities which it is customary for psychologists to draw.

Orthogonality of the square-root factors. Since square-root factors are orthogonal, it may at first sight seem strange that several factors may be extracted in what might appear to be the same area. For example, Factor 3, labeled "Executive Ability" considers (among other things) ability to organize personnel, Factor 4, labeled "Leadership," stresses ability for giving directions and assuming a dominant role, and Factor 9, labeled "Ability to Motivate Others," describes a talent for group activity and for effective teamwork with co-workers. Moreover, some items appear in two lists, viz., "Quick to praise a man for a job well done," "An extremely good organizer of personnel," "He is good at organizing new activities," "He doesn't seem to realize he's just a cog in a large wheel."

Nevertheless, each factor has a somewhat different emphasis. Factor 3 stresses planning and organizational ability, Factor 4, leadership and the giving of orders, and Factor 9, cooperation and sympathy for others. Most of the items in each list are peculiar to that factor. These items which appear in two lists may be presumed to be factorially complex, embodying some element of one factor and some element of another.

No doubt, by different placement of axes, some more comprehensive factor, extending over the entire area of personnel control and interpersonal relations, could be extracted, with subsidiary factors making the distinction between organizational ability, leadership, and cooperation. Any such solution would certainly be acceptable. Yet the way the variance has been partitioned by the square-root method seems equally acceptable in indicating the principal conceptual distinctions made by the supervisors in their descriptions.

An even more striking instance of apparent overlapping is between Factor 5, labeled "Personal Charm," and Factor 13, labeled "Changeability of Mood." Factor 13 not being reported in this monograph, it will suffice to note that the four items with highest loadings are: "Changeable in his attitudes," "Inclined to 'pop off' on occasion," "Gets mad if things don't go to suit him," and "He thinks he puts in too long hours." In contrast to the calm and relaxed personality of Factor 5, mechanics of the type portrayed by Factor 13 seem to be changeable, irritable, and given to outbursts of temper. But the cluster of negatively toned items in Factor 13 is not completely antithetical to the cluster of positively toned items in Factor 5. Factor 13 seems to be principally concerned with high emotionality, and Factor 5 with social manner. In the correlation matrix, the correlations between the two sets of items are well short of −1.00. This means that supervisors sometimes give the same response to both a positively toned item and a negatively toned item which appears to be antithetical. This may sometimes be the result of carelessness in responding to the inventory, but it seems reasonable to believe that no man's behavior is consistently good, poor, or average. This tendency to mark, say, "true" to antithetical phrases might on this line of reasoning be expected to be

especially characteristic of supervisors rating "average" mechanics. It may not be at all inconsistent for a supervisor to report a certain mechanic to be changeable in attitude, and yet to be pleasant to talk to and to possess a pleasant voice. These negative interitem phi coefficients of much less than unity probably provide evidence that the halo effect was to some extent overcome by the raters. The fact that items of the type included in Factors 5 and 13 tend to have lower criterion correlations supports this explanation. The fact that it is often difficult in our language to find exact synonyms and exact antonyms is a further indication of the complexity of our behavior.

V. Relation of the Factors to Supervisory Ratings of Job Proficiency

In this section we consider: (*a*) the average criterion correlation for the ten most highly loaded items of each factor, (*b*) the pattern of job performance represented by items with high criterion correlations, and (*c*) the nature of the items which appear to be unrelated to ratings of either good or poor performance.

Average criterion correlations for the ten most highly loaded items for each factor. The criterion correlations will be recalled to be the phi coefficients between each item and the "best-poorest" classification, with average mechanics excluded from the sample. Since these judgments of "best" and "poorest" were made by the same supervisors who provided the item ratings, they do not represent an independent measure of job proficiency. The criterion correlations may therefore be spuriously high, both for this reason and because they are based on the extremes of the sample. The correlations are nevertheless useful for our present purpose, which is merely that of determining the pattern of behavior which supervisors consider to be characteristic of good mechanics.

Table 2 presents the average criterion correlations for the ten items with highest loadings on each factor. In the two previous studies (6, 7), factors dealing with practical efficiency, good judgment, foresight, etc., had been found more predictive than those relating to sociability, character, degree of emotionality, and other personality attributes. Results for the Survey Inventory agree with those already reported. The most predictive factor is the first; this, it will be recalled, stresses practical efficiency and good organization. The least predictive factor is the one labeled "Personal Charm." It seems to make rather little difference to quality of work whether or not a mechanic is liked by his associates.

TABLE 2

Average Criterion Correlations for the Factors

Factor number	Factor title	Average criterion correlation
1	General job efficiency	.83
10	Mechanical proficiency	.71
3	Executive ability	.70
2	Social maladjustment	−.68
9	Ability to motivate others	.67
7	Willingness and adaptability	.66
6	Resourcefulness	.58
4	Leadership	.57
8	Orderliness	.54
5	Personal charm	.30

Note—Correlations are based on descriptions of "best" and "poorest" mechanics. ("Average" mechanics excluded.)

The Survey Inventory factors are, on the whole, more predictive than those for the other two inventories. This difference will be discussed in Section VI of this report.

The pattern of performance indicated by items with large criterion correlations. Tables 3 and 4 list items with criterion correlations greater than or equal to .70. Items more commonly used to describe "best" mechanics appear in Table 3; those more often applied to "poorest"

TABLE 3

CRITERION CORRELATIONS FOR ITEMS WITH HIGH POSITIVE PREDICTIVE VALUE ($\phi > .70$)

Item no.	Correlation coefficient	Item
187	.870	Fits well into the organization
116	.865	Goes over own work to see that it was done correctly
8	.857	Seems to have a good future as a mechanic
191	.846	Sets a good example through his habits of work
180	.838	He gives his best effort to whatever he is doing
91	.836	Very valuable in a new operation
92	.834	He should develop into one of the leading men in the crew
163	.834	Handles additional and special responsibilities well
161	.812	Works well without supervision
169	.812	Works well without a lot of explaining
174	.811	Knows how to organize to get right things done at right time
99	.809	Is a better man than the average we have had in past years
131	.809	Sees what will be needed later and gets ready for it
145	.808	Can take over in an emergency
179	.807	Is determined to make good
123	.799	On the lookout for better ways of doing the job
111	.797	He makes the best use of his ability
6	.795	Shows good foresight in his planning
106	.791	Very good at going ahead alone
51	.788	His advice is asked by others
200	.784	Is always a willing worker
86	.775	Does jobs in order of importance
152	.773	Respected by all who know him
34	.769	Uses good judgment in most situations
17	.749	Takes precautions to prevent damage to equipment
190	.748	Makes the best of every bad situation
144	.745	Helps others with their work whenever possible
90	.731	Selects proper Tech. Orders and makes correct use of them
41	.729	Has won nearly everybody's confidence
188	.729	Would be very difficult to replace
196	.729	Obtains co-operation from other people
27	.728	Checks on the condition of the airplane and its equipment prior to flight
61	.728	He can organize his ideas effectively
154	.723	Has exceptional mechanical ability
33	.721	He learns new jobs quickly
159	.716	Usually assembles or disassembles parts in proper sequence
171	.715	Provides just the "spark" that is needed for effective teamwork
70	.714	Makes plans fit in with those of fellow workers
36	.710	Readily understands and carries out instructions
28	.705	Usually tackles a job with enthusiasm
74	.702	He accepts full responsibility for his own work
24	.700	Knows how to put best foot forward

Note—Correlations are based on descriptions of "best" and "poorest" mechanics. ("Average" mechanics excluded.)

mechanics are presented in Table 4. The good mechanic will be seen to be described as:

(*a*) cooperative—he gets on well in the organization, is helpful to others, and succeeds in getting their cooperation;

(*b*) keen to do his best—he approaches a job enthusiastically, does the best with it that he can, and wants to make good;

(*c*) responsible—he works well without supervision, can take over in an emergency, is good at going ahead by himself, and makes a success of any special responsibilities;

(*d*) versatile and flexible in his ways—he watches for better ways of doing the job, and is useful in new operations;

(*e*) accurate—he makes sure that his work is correct;

(*f*) foresightful with a good sense of proportion—he carries out jobs in the right order of importance, and gets ready for what is needed.

Some items in the list consider the ability level of the mechanic. The good

TABLE 4

CRITERION CORRELATIONS FOR ITEMS WITH HIGH NEGATIVE PREDICTIVE VALUE

Item no.	Correlation coefficient	Item
95	−.848	Doesn't do his share of the work
65	−.824	Takes far too many breaks
114	−.806	Loses too much time in waste motion
170	−.799	Never has things ready when needed
66	−.798	Seldom plans work ahead
88	−.797	Never notices things to be done
67	−.795	Doesn't seem to realize he's just a cog in a large wheel
121	−.795	Always ready with an excuse
146	−.780	Wastes time walking around and talking to others
53	−.761	He abuses privileges
79	−.759	His work requires more than a normal check-up
138	−.759	Does not take important matters seriously
192	−.759	Can't seem to make ends meet
47	−.756	Thinks mostly of himself and not of other crew members
130	−.752	Says one thing and does another
148	−.736	Exaggerates too much
1	−.729	Is frequently late for work
156	−.728	Is a routine worker, doing only what is required
109	−.718	Has a poor attitude
87	−.717	Unfairly criticizes policies of his superiors
186	−.716	Wastes fuels, lubricants and other supplies
118	−.709	Often picks up any old wrench to do a job
105	−.707	He criticizes men who are better than he is
167	−.706	Gripes about the least thing
112	−.703	Uses a "line" to try to impress others

Note—Correlations are based on descriptions of "best" and "poorest" mechanics. ("Average" mechanics excluded.)

mechanic is described as having high mechanical aptitude and being able to learn new jobs rapidly. There is specific reference to selecting appropriate Technical Orders and to assembling parts in proper sequence. Other items stress the practical application of knowledge and abilities.

It is interesting to notice that the good mechanic is rather generally respected for his work. We are told that he wins nearly everybody's confidence, and that others go to him for advice. Other items in the list describe successful job performance in such general terms that we are supplied with no new information as to its specific nature. Examples of such items (which are nevertheless highly predictive) are "He seems to have a good future as a mechanic" and "He would be very difficult to replace."

The items with high negative coefficients, i.e., those which are more characteristic of poor mechanics, reinforce the above picture. The poor mechanic is portrayed as lazy, careless, and uncooperative. He has low morale, fails to plan ahead, and is never ready on time. Untrustworthy and inefficient, he says one thing and does another, and loses time in waste motion. Perhaps most significantly of all, he is described as a routine worker who does only what is required and fails to take important matters seriously.

Items of low predictive value. Table 5 lists items with criterion correlations lower than .20. As in the earlier studies, the social personality of the mechanic bears little relation to the rating he is given by his supervisor. It matters little whether he is easygoing and at ease in

TABLE 5

CRITERION CORRELATIONS FOR ITEMS WITH LOW PREDICTIVE VALUE ($\phi < .20$)

Item no.	Correlation coefficient	Item
81	.064	Rubs people the wrong way
101	.070	Easy going
164	.121	Has a bold, direct manner
71	.171	Has a pleasant voice
16	.180	Is at ease in any situation
35	−.007	Often uses gestures to put across his ideas
100	−.046	Lets others take advantage of him
149	−.046	Is always asking for advice
185	−.088	Gets resentful if property or other rights are trespassed on
153	−.153	Worries over possible misfortunes
160	−.183	Fears criticism from superiors

Note—Correlations are based on "best" and "poorest" mechanics. ("Average" mechanics excluded.)

any social situation or is irritable and liable to worries and fears.

VI. COMPARISON OF THREE TYPES OF RATING ITEM

In the research series of which this study is a part, factor analyses were made of items drawn from three sources. The *Descriptive Inventory* (7) was derived from supervisors' interview descriptions of aircraft mechanics, the *Factorial Inventory* (6) from factor-analytic studies of personality and ability, and the *Survey Inventory,* reported here, from rating scales and questionnaires designed to measure job performance in various fields. In this section, results from the three studies will be compared.

The three inventories were administered to different samples of supervisors of aircraft mechanics under similar experimental conditions. The only material change was a decreased proportion of "average" ratings, relative to "best" and "poorest," in the Survey Inventory. The number and proportion of ratings of each type in each study are presented in Table 6. The increased proportion of extreme ratings in the Survey Inventory does not affect the criterion correlations, since they are based upon "best" and "poorest" ratings only. However, in the factor analyses there might be a greater concentration of item variance in the early factors of the Survey Inventory. This possibility should be kept in mind in the comparisons which follow.

Table 7 compares (*a*) the distribution of variance and (*b*) the average criterion correlation, for the first 10 factors of the three inventories. If, for the rating of job performance, we were obliged to re-

TABLE 6

COMPARISON OF SAMPLES IN THE THREE INVENTORIES

Inventory	Number of ratings				Percentage of ratings		
	Best	Average	Poorest	Total	Best	Average	Poorest
Descriptive	112	224	92	428	26.2	52.3	21.5
Factorial	95	194	94	383	24.8	50.7	24.5
Survey	148	179	137	464	31.9	38.6	29.5

TABLE 7

COMPARISON OF THE DISTRIBUTION OF VARIANCE AND OF THE AVERAGE CRITERION CORRELATION IN THE FACTORS OF THE THREE INVENTORIES

Inventory	Contribution to variance		Average criterion correlation	
	Factor 1	Factors 2–10	Factor 1	Factors 2–10
	per cent	per cent		
Descriptive	20.6	15.3	.74	.49
Factorial	9.0	23.4	.41	.41
Survey	26.8	17.0	.83	.60

Note—Correlations are based on "best" and "poorest" mechanics. ("Average" mechanics excluded.)

strict ourselves to items drawn from a single factor of a single inventory, the first factor of the Survey Inventory would have to be our choice. It defines better than any other the qualities considered by supervisors to be characteristic of a good mechanic. The criterion correlations are higher, and more item variance is accounted for, than for any other factor.

A rather different pattern emerges if the results for Factors 2-10 of each study are considered. The Factorial Inventory is seen to be more comprehensive in coverage than the Survey Inventory, but its items tend to be less job-centered and less predictive. The Descriptive Inventory falls between the other two in respect to predictive power.

The different areas of behavior described by each inventory. Differences in the subject matter of the inventories may perhaps be summarized most readily by making an a priori classification of the factors, and then attempting to determine the extent to which each behavioral area is represented in each inventory. The statistical orthogonality of the square-root factors need not preclude us from doing this, since the presence of factorially complex items in several factors indicates their semantic interrelatedness. (See the discussion of orthogonality and overlapping of factors in the later part of Section IV.)

Because of the multiplicity of factors, the listing will be restricted to the ten largest factors in each study. Table 8 presents this classification. The grouping of factors is to some extent arbitrary, and alternative classifications are possible. Results are so clear, however, as to leave little doubt as to the nature of the differences in content.

1. *Practical ability.* By "practical ability," we mean the capacity to make decisions quickly, carry out jobs in order of importance, find better ways of doing a job, explain matters adequately, organize well, and plan work in advance. This aspect of job proficiency takes a central position in each inventory. Seven factors in this area appear in Table 8, and criterion correlations are in most cases high.

2. *Sense of responsibility toward work.* There are four factors in this area in the Descriptive Inventory, and one in the Survey Inventory. A mechanic's willingness and dependability seem to be the aspect of job behavior which is discussed at greatest length by the supervisors. As might be predicted, criterion correlations in this area are high.

3. *Pattern of interests.* Interest in the job is not well represented in any of the three inventories. The Descriptive Inventory contains a factor entitled "Interest in Aircraft Maintenance," and the Survey Inventory factor of "Willingness and Adaptability" might perhaps also have been included in this grouping. In both factors, the items are rather broad and nonspecific. The Factorial Inventory

TABLE 8

COMPARISON OF THE TEN MAJOR FACTORS IN THE DESCRIPTIVE, FACTORIAL, AND SURVEY INVENTORIES

Area of behavior	Factor number	Average criterion correlation	Factor title
1. Practical ability	D6	−.71	Failure to use knowledge effectively
	D7	.41	Teaching capacity
	F3	−.71	Tendency to indecision
	F4	.58	Practical ability
	S1	.83	General job efficiency
	S3	.68	Executive ability
	S10	.71	Mechanical proficiency
2. Sense of responsibility towards work	D1	.74	Sense of responsibility
	D3	.50	Willingness for work
	D4	−.59	Laziness and lack of initiative
	D8	.58	Industriousness
	S7	.66	Willingness and adaptability
3. Pattern of interests	D2	.41	Interest in aircraft maintenance
	F6	.48	Cultural interests
4. Intellectual ability	D9	.55	Memory
5. Personality characteristics in the job situation	F5	−.58	Lack of cooperation
	S6	.58	Resourcefulness
	S8	.54	Orderliness
	S4	.57	Leadership
	S9	.67	Ability to motivate others
6. Social adjustment	F2	−.62	Social immaturity
	F7	−.06	Shyness
	F8	.16	Sociability
	F9	.18	Submissiveness
	S2	−.68	Social maladjustment
	S5	.30	Personal charm
7. Emotional adjustment	F1	−.41	Tendency to neuroticism
	F10	−.31	Emotional sensitivity
8. Character	D5	−.38	Weakness of character
	D10	.23	Self-control

Notes—1. Correlations are based on "best" and "poorest" mechanics. ("Average" mechanics excluded.)

2. D, F, and S indicate that the factors are from the Descriptive, Factorial, and Survey Inventories respectively.

contributes a factor of "Cultural Interests" to this area. This serves to indicate the different and much less job-relevant type of item utilized by factor-analysts in their studies of personality and ability.

4. *Mental abilities.* Only slight reference is made to ability and to job knowledge. In the report on the Descriptive Inventory (7, p. 232), we commented on the fact that supervisors stressed motivation and practical efficiency, so that no clearly defined factors of memory, reasoning, and problem-solving ability emerged. Items were included in the Factorial Inventory to assess mental abilities. Factors of creativity, mental alertness, etc., emerged, and the results leave no doubt that all-round intellectual dullness is a variable contributing to poor performance on the job. However, these factors all account for a rather small proportion of the variance. This means that the differences between mechanics are mostly described in such a way as to be attributable to factors of a more practical kind. Items dealing with sharpness of mind, ability to learn quickly,

etc., tend to appear along with items describing general job efficiency, organizational capacity, and the like, rather than by themselves. In no study is there extended reference to a mechanic's knowledge of his job.

5. *Personality characteristics in the job situation.* Personality traits seem to divide into two groups: (*a*) those which are relevant to the job situation, such as being orderly, resourceful, and able to motivate others; (*b*) those which are only slightly or not at all relevant in the job situation, such as degree of shyness. There are five factors under the heading of "Personality characteristics in the job situation." Four of these are from the Survey Inventory. Probably because the items for this inventory were written with specific reference to the job situation, the stress in the personality-type items is upon degree of cooperativeness, ability as a leader, etc.

6. *Social adjustment.* The Factorial Inventory items deal to a greater extent than the others with the entire pattern of a man's interpersonal relationships, and his ability to manage adequately in social situations. Four of the six factors in this area appear in the Factorial Inventory. Criterion correlations are in general lower for these factors. The shy and introverted mechanic seems to be quite acceptable. On the other hand, the hostile and trouble-making mechanic is not.

7. *Emotional adjustment.* The two factors in this area are, as might be expected, from the Factorial Inventory.

8. *Character.* The Descriptive Inventory makes greater reference than any other to defects of character—heavy drinking, irresponsibility in money matters, and the like. Criterion correlations are, as a rule, rather low.

From Table 8, a summary statement can be made of the distinctive characteristics of each of the three inventories.

The Descriptive Inventory (phrases supplied by supervisors) stresses a mechanic's willingness for work, dependability, and sense of responsibility. Furthermore, there is more in this inventory than in either of the others about a mechanic's moral habits—i.e., about his monetary and drinking habits, his trustworthiness, his punctuality, etc. These are probably areas of behavior where there are likely to be disputes between supervisor and mechanic, so that any deficiences are strongly impressed upon the supervisor's attention. The supervisors tend to use evaluative rather than analytical descriptions.

The Factorial Inventory (phrases drawn from factor-analytic studies reported in the literature) stresses the mechanic's social and emotional adjustment—i.e., his emotional sensitivity and variability, his shyness, tendencies to submissiveness, etc. In general, these aspects of personality are not very closely related to job performance. The criterion correlations are lower than for any other area of behavior. This finding must be qualified in one important respect. There are factors of "social immaturity" and "social maladjustment" which portray "difficult" and somewhat antisocial personalities (as opposed to merely shy and submissive individuals), and these mechanics are rated poor. In addition, those factors which relate more directly to social behavior on the job itself (e.g., leadership ability, ability to obtain cooperation from others) have rather high criterion correlations.

The Survey Inventory (phrases obtained from researchers in applied psy-

chology) stresses practical ability. It also yields factors which describe what we have called "Personality characteristics of the job situation," viz., resourcefulness and orderliness. Its factors of social adjustment are rather strongly job oriented. Motivation is stressed less in the Survey Inventory than in the Descriptive Inventory, but there is greater emphasis upon efficiency and good interpersonal relations. The Survey Inventory items are less evaluative but more analytic than those of the Descriptive Inventory, and more job centered than those of either of the other inventories.

This greater "job-centeredness" of the Survey Inventory is reflected in its appreciably higher criterion correlations. Thirty-three per cent of the Survey Inventory criterion correlations are greater than .70. Only 18 per cent of the Descriptive Inventory items and 10 per cent of the Factorial Inventory items are as high as this. Hence, if we had to confine ourselves to any single one of the three inventories, the Survey Inventory would be the most reasonable choice.

The over-all picture of the good mechanic presented by the three studies is that of a man who has in mind the needs and demands of his job, who is willing to work hard, and who is vigorous and mentally alert, displaying good judgment and powers of decision. He is precise, orderly, and dependable; yet at the same time he displays initiative and acts for himself. He is efficient and practical. *More is said about the use he makes of his abilities than about the abilities themselves. The qualities which have been listed are probably useful assets in any form of work.* Little is said about the special features of a mechanic's job situation which distinguish it from other types of work.

One of the important determinants of quality of performance on the job seems to lie in differing standards of value: we can differentiate between the mechanic who cares about his work, is ambitious, and wants to get on, and the one whose interest lies in getting privileges and time off and avoiding work. A second main line of distinction is between the mechanic who is systematic and orderly and his associate who is inefficient and lacking in common sense. In general, these items are strongly job-centered, and the occupational characteristics which they describe are not always easily expressed in the standard terms used for accounts of ability and personality structuring.

The dependence of factorial results upon the sampling of variables. The results of the three studies show very clearly how content differs from one inventory to another. Obviously selection of items in factorial studies of this type is a matter of the utmost experimental importance. Before any final and definitive factorial description of the area can be provided, *some logical definition is needed of a population of items from which random samples of items may be drawn.* Once the population of variables can be determined, then the correlational configuration will tend to be similar from one factorial study to another (provided the sample of variables was large, and the persons tested in the various studies also formed random samples from a defined population). Given this similarity of the correlational configuration, the clusters obtained from one random sample of items will then tend to agree with the clusters obtained from another random sample.

The problem then is in the definition of the population of variables. There

seem to be at least two requirements: (*a*) to establish the possibility of enumeration of all members of the population or of an unbiased and sufficiently large proportion of the members of the population to provide a basis for random sampling, (*b*) to demonstrate that the population so defined provides adequate representation of the area of behavior to be investigated.

Whenever we are operating with environmental givens (i.e., variables already present in the psychological environment, as opposed to artifacts constructed at will by the investigator), it is generally not difficult to formulate some criterion for inclusion in the population, and accordingly to devise some random basis for sampling. For example, current semantic usage can provide a basis for sampling. The complete set of adjectives appearing in an English dictionary can be listed, as has been done by Allport and Odbert (1), and the sample drawn from these. Cattell (3, p. 216) prepared a comprehensive list of "basic trait elements" in this way. Likewise environmental situations can be sampled. Brunswik and his co-workers (2, pp. 41-46), after protesting that many laboratory experiments use unimportant variables, unrepresentative of the environment and interlocked in some artificial way, have made effective use of sampling various environmental situations in their studies of size constancy.

Our procedure in selecting items for the three inventories was somewhat similar. For the Descriptive Inventory (7) phrases were sampled from the descriptions of mechanics made by their supervisors. The population in this case consists of the various phrases currently used by Air Force supervisors to describe the mechanics under their control. The Factorial Inventory (6) was developed from the population of items used in published factor analyses in the area of personality, and the Survey Inventory from the population of published items in rating scales and questionnaires in industrial psychology.[9]

The principal difficulty is in meeting the second requirement for a population of variables. No one of our three proposed definitions of the population of job-knowledge descriptions proved to be sufficiently broad to subsume all aspects of job performance. For example, reasons for interest or disinterest in work are not adequately elicited by any inventory. Likewise, no one provides a sufficiently explicit account of the role played by job knowledge in job performance. To study these areas, further items would have to be prepared. *Evidently the task of item-writing is not yet at an end, despite the large number of scales prepared by psychologists during the last fifty years.*

This appearance of precise definition of the population may be illusory even when operating with the population of dictionary adjectives, as Cattell did. Many adjectives have various shades of meaning, and often no instructions are given to the subjects requiring them to select one of these meanings rather than any other. Indeed, meaning can generally be better indicated by phrases, which provide a context, than by words in isolation.

Once, however, we are obliged to conclude that there is a place for further

[9] The sampling in this latter case was modified by the attempt to tap previously unrepresented areas of behavior, but the general argument is not thereby affected, since further inventories similar to the Survey Inventory could obviously be obtained from the original collection of items.

item-writing by the investigator, then it follows that we are at present only partially able to achieve a definition of a population of items. So long as the investigator is free to create new items at will, it seems to be premature to try to provide a rigorous delimitation of the population of items from which a sample is to be drawn.

The function of the factor analysis. Because we are not yet in a position to define sampling procedure exactly, the development of a satisfactory rating scale for job performance has therefore to depend upon the progressive selection, refinement, and supplementation of items. The principal function of the factor analysis reported here has been to provide an empirical basis for preparing a briefer scale. The interview situation can then be used to assist in elucidation of the factors represented therein. After describing a mechanic in terms of the items, a supervisor can be asked further questions, e.g., with respect to the reasons for unusually high motivation, whether it indicates a man's interest in his own advancement, or his liking for mechanical assignments, or a favorable attitude toward the Air Force and its organization. These supplemental questions can be framed much more appropriately around the structure of the factors than with respect to individual items. The factor analyses, therefore, represent an initial step toward the better definition of the population of items for the rating of mechanics' performance.

VII. Summary

The research here reported is the last of three studies designed to investigate the different psychological correlates of job proficiency in the field of aircraft mechanics. Inventory items hypothesized to be related to job performance in this field were assembled from various sources, and supervisors were required to describe mechanics in terms of these phrases. This report considers the factorial structure of the items, and the relation of each item to the supervisors' over-all ratings of the mechanics.

The report is also designed to provide an example of application of the square-root method of factor analysis, as modified by Wrigley and McQuitty (9). The method has been devised for use with correlation matrices which are too large to be analyzed by standard procedures. There is a brief outline of the criticisms generally made of the square-root method, and the modifications introduced in an attempt to overcome these deficiencies.

Items in present study were systematically drawn from a set of rating scales and questionnaires which had been designed by various psychologists to measure different aspects of job proficiency. The items in the initial sample were revised in accordance with the results of a preliminary administration. The revised scale of 200 items, known as the Survey Inventory, was then administered to 464 supervisors of Air Force Aircraft and Engine Mechanics. They were required to describe a "best," "poorest," or "average" mechanic of their own choosing in terms of "true-false" responses to the items.

A square-root factor analysis was then made of the correlations between these item responses. The ten leading factors were named: (*a*) General Job Efficiency, (*b*) Social Maladjustment, (*c*) Executive Ability, (*d*) Leadership, (*e*) Personal Charm, (*f*) Resourcefulness, (*g*) Willingness and Adaptability, (*h*) Orderliness, (*i*) Ability to Motivate Others, (*j*) Mechanical Proficiency.

Phi coefficients were also calculated be-

tween the inventory items and the "best-poorest" dichotomy. These correlations indicate the factors and the individual items which supervisors judge to be most relevant to job proficiency, and thereby serve to define more precisely supervisors' conceptions of the nature of good and poor job performance.

These results were then compared with those obtained from the analysis of (*a*) the Descriptive Inventory (7) (where items were derived from relatively unstructured descriptions of "best" and "poorest" mechanics by their supervisors) and (*b*) the Factorial Inventory (6) (where items were derived from factor-analytic studies). The inventories agree in the findings that practical capabilities are more necessary in a successful mechanic than general intellectual ability, and that lack of motivation and a poor sense of responsibility are more detrimental than a poor level of socioemotional adjustment. Each inventory tends, however, to have a distinctive coverage of its own. The Descriptive Inventory stresses a mechanic's willingness for work and his dependability, the Factorial Inventory his social and emotional adjustment, and the Survey Inventory, his practical ability. The items of the Survey Inventory are shown to be of broader coverage and somewhat more predictive and job-centered than those in the two preceding inventories. Hence the Survey Inventory would be the most reasonable choice if a single one of the three were to be selected for assessing job proficiency. Because of the distinctive nature of each inventory, however, a shortened scale may be expected to be a better measuring instrument if based on all three inventories than if developed from any single one.

Appendix

SURVEY INVENTORY FOR AIR FORCE MAINTENANCE PERSONNEL

Purpose

This inventory is part of a research study on the attitudes and work habits of Airplane and Engine Mechanics. Your assistance is needed in carrying out this research because of your experience and close association with men in the maintenance field.

Instructions

Think back over the crews of Airplane and Engine Mechanics you have worked with during the last two years. Think of a person who is, in your opinion, just an *AVERAGE*[10] mechanic; that is, a mechanic who is neither especially good, nor especially poor. Do *not* pick out a crew chief or supervisor when you make this selection.

Statements are listed on the following pages which will help you describe the mechanic you now have in mind. Say each statement to yourself and decide whether or not it fits this mechanic. If it does, circle the T (for true) at the left of the statement; if not, circle the F (for false).

Decide on each statement before going on to the next. *Guess* whenever you are not certain whether or not a statement describes the man. Be sure to answer all statements as either true or false.

NOTE: All information will be held in strictest confidence and used for research purposes only. It WILL NOT affect you or the mechanic in any way.

Survey Inventory

T	F	1. Is frequently late for work
T	F	2. Is unwilling to lend a helping hand
T	F	3. Has a very sharp mind
T	F	4. Likes to make decisions
T	F	5. Talks a lot to everybody
T	F	6. Shows good foresight in his planning
T	F	7. Lacks snap in getting the work done
T	F	8. Seems to have a good future as a mechanic

[10] Other supervisors received directions to describe the "Best" mechanic they had known during the previous two years, and still others, to describe the "Poorest" mechanic.

T F 9. Takes pride in his health
T F 10. Couldn't direct without irritating people
T F 11. He remains calm under pressure
T F 12. Has slow reactions
T F 13. Can be used effectively on several different types of work
T F 14. Lacks confidence in own opinions
T F 15. Doesn't listen to suggestions
T F 16. Is at ease in any situation
T F 17. Takes precautions to prevent damage to equipment
T F 18. Arouses ambition in fellow mechanics
T F 19. Usually sees the humorous side of things
T F 20. He thinks he puts in too long hours
T F 21. Likes to take on responsibilities
T F 22. Has a good imagination
T F 23. Criticizes co-workers
T F 24. Knows how to put best foot forward
T F 25. Is excellent for instructing beginners
T F 26. His personal conduct cannot be criticized
T F 27. Checks on the condition of the airplane and its equipment prior to flight
T F 28. Usually tackles a job with enthusiasm
T F 29. Conforms to regulations and policies
T F 30. Does not improve with experience
T F 31. Sometimes acts childish
T F 32. Never quits ahead of time
T F 33. He learns new jobs quickly
T F 34. Uses good judgment in most situations
T F 35. Often uses gestures to put across his ideas
T F 36. Readily understands and carries out instructions
T F 37. Has about reached limit of his abilities
T F 38. Will trample over anyone to benefit himself
T F 39. Usually quick and accurate in emergencies
T F 40. Has poor posture
T F 41. Has won nearly everybody's confidence
T F 42. Often takes rumors seriously
T F 43. Plenty of military snap and bearing
T F 44. Doesn't clean tools before putting them away
T F 45. Stimulates co-workers to think
T F 46. Can stand kidding
T F 47. Thinks mostly of himself and not of other crew members
T F 48. Does very little original thinking
T F 49. Seeks and does additional tasks beyond those required
T F 50. Makes promises he doesn't keep
T F 51. His advice is asked by others
T F 52. Apparently not physically fit
T F 53. He abuses privileges
T F 54. Hesitates in making decisions on ordinary everyday questions
T F 55. Frequently gives short answers
T F 56. Has trouble adjusting himself to changed conditions
T F 57. Is inclined to be impatient with others
T F 58. Uses parts catalogue and stock list correctly in ordering parts
T F 59. Lets difficulties get him down
T F 60. He makes definite decisions and defends them with courage
T F 61. He can organize his ideas effectively
T F 62. Expects too rapid advancement
T F 63. He is apt to be master of a situation if it needs a leader
T F 64. Needs to be prodded occasionally
T F 65. Takes far too many breaks
T F 66. Seldom plans work ahead
T F 67. Doesn't seem to realize he's just a cog in a large wheel
T F 68. Is familiar with main trouble spots of an airplane
T F 69. He thinks his supervisors are too strict
T F 70. Makes plans fit in with those of other fellow workers
T F 71. Has a pleasant voice
T F 72. Forgets to return borrowed tools
T F 73. Usually finds some way to "crack a hard nut"
T F 74. He accepts full responsibilty for his own work
T F 75. Allows his emotions to color his judgment
T F 76. Easy to talk to
T F 77. Gets mad if things don't go to suit him
T F 78. Quick to size up a situation
T F 79. His work requires more than a normal check-up
T F 80. Tends to see the good side of things
T F 81. Rubs people the wrong way
T F 82. He seldoms asks for any time off
T F 83. Boosts the morale of any group in which he is working
T F 84. Is very selfish
T F 85. Uses correct torque on bolts and nuts
T F 86. Does jobs in order of importance
T F 87. Unfairly criticizes policies of his superiors
T F 88. Never notices things to be done
T F 89. Feels that he owes nothing to anybody
T F 90. Selects proper Tech. Orders and makes correct use of them

T F 91. Very valuable in a new operation
T F 92. He should develop into one of the leading men of the crew
T F 93. Inclined to "pop off" on occasion
T F 94. Risks getting in bad with superiors to stand up for his fellow workers
T F 95. Doesn't do his share of the work
T F 96. Can't be told anything
T F 97. Can talk intelligently on almost any topic
T F 98. Cannot handle several details of his job at the same time
T F 99. Is a better man than the average we have had in past years
T F 100. Lets others take advantage of him
T F 101. Easy going
T F 102. Turns off power or motor equipment when not in use
T F 103. Is usually dressed neatly
T F 104. Gets help when in difficulties
T F 105. He criticizes men who are better than he is
T F 106. Very good at going ahead alone
T F 107. Always pleasant and cheerful
T F 108. He always waits his turn
T F 109. Has a poor attitude
T F 110. Always shows proper respect toward superiors
T F 111. He makes the best use of his ability
T F 112. Uses a "line" to try to impress others
T F 113. Resents being given a rush job
T F 114. Loses too much time in waste motion
T F 115. Wants to adjust himself to new situations
T F 116. Goes over own work to see that it was done correctly
T F 117. His appearance creates a distinctly favorable impression
T F 118. Often picks up any old wrench to do a job
T F 119. Takes pride in group accomplishment
T F 120. Has "jumpy" nerves
T F 121. Always ready with an excuse
T F 122. Goes his own way regardless of others
T F 123. On the lookout for better ways of doing the job
T F 124. Changeable in his attitudes
T F 125. Not as tactful in criticizing as he should be
T F 126. Is not very sociable
T F 127. Does everything possible to keep maintenance costs down
T F 128. Avoids doing things which do not reflect credit on him
T F 129. Makes mistakes in judging the character and ability of others
T F 130. Says one thing and does another
T F 131. Sees what will be needed later and gets ready for it
T F 132. Is a never-tiring worker
T F 133. Never cocky or over-bearing
T F 134. Plans ahead for almost any emergency
T F 135. Is helpless when working in awkward positions
T F 136. Dissatisfied with his present job
T F 137. Is careless of personal appearance
T F 138. Does not take important matters seriously
T F 139. He butts in on others' responsibilities
T F 140. Would be willing to begin in any kind of job to prove his ability
T F 141. Resents criticisms or suggestions
T F 142. Makes trouble over little things
T F 143. Reports on time for scheduled appointments, meetings, formations, etc.
T F 144. Helps others with their work whenever possible
T F 145. Can take over in an emergency
T F 146. Wastes time walking around and talking to others
T F 147. His quarters are usually neat
T F 148. Exaggerates too much
T F 149. Is always asking for advice
T F 150. Always does things in one particular way
T F 151. He has made a good social adjustment on the job
T F 152. Respected by all who know him
T F 153. Worries over possible misfortunes
T F 154. Has exceptional mechanical ability
T F 155. Often waits unnecessarily for directions
T F 156. Is a routine worker, doing only what is required
T F 157. He is quarrelsome
T F 158. Able to by-pass red tape when necessary
T F 159. Usually assembles or disassembles parts in proper sequence
T F 160. Fears criticism from superiors
T F 161. Works well without supervision
T F 162. He seems to know when to keep his mouth shut
T F 163. Handles additional and special responsibilities well
T F 164. Has a bold, direct manner
T F 165. Quick to praise a man for a job well done
T F 166. Discusses plans frequently with superior
T F 167. Gripes about the least thing
T F 168. Will really go to bat for things when he has to

T F 169. Works well without a lot of explaining
T F 170. Never has things ready when needed
T F 171. Provides just the "spark" that is needed for effective teamwork
T F 172. A one-job man, no wide grasp of maintenance
T F 173. Tries to flatter crew chief
T F 174. Knows how to organize to get right things done at right time
T F 175. Thinks his work is too monotonous
T F 176. He is considered a "good sport"
T F 177. Teaches himself how to operate equipment without supervision
T F 178. Complaints are made (more often than average) on the quality of his work
T F 179. Is determined to make good
T F 180. He gives his best effort to whatever he is doing
T F 181. An extremely good organizer of personnel
T F 182. Prefers to be a follower rather than a leader
T F 183. Makes allowance for the limitations of others
T F 184. Always wanting sympathy
T F 185. Gets resentful if property or other rights are trespassed on
T F 186. Wastes fuel, lubricants, and other supplies
T F 187. Fits well into the organization
T F 188. Would be very difficult to replace
T F 189. He is good at organizing new activities
T F 190. Makes the best of every bad situation
T F 191. Sets a good example through his habits of work
T F 192. Can't seem to make ends meet
T F 193. Unwilling to stick his neck out
T F 194. Inclined to pay much attention to his aches and pains
T F 195. He likes the way the maintenance squadron is run
T F 196. Obtains co-operation from other people
T F 197. Knows his own abilities well
T F 198. He accepts decision of the majority without showing his displeasure when the decision is against him
T F 199. Fails to make a good first impression
T F 200. Is always a willing worker

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